	PAVEMENT TECH NOTES
	FLEXIBLE PAVEMENT DESIGN EXAMPLES - NEW CONSTRUCTION
	September 28, 2006

Editors Note: The following information was extracted from the July 1, 1995 edition of the Highway Design Manual, Chapter 600 and updated to reflect current practices.

Introduction

Flexible pavement structures are constructed of a flexible pavement (typically asphalt) surface layer that is placed over a treated or untreated base layer and an untreated subbase layer.

Flexible pavement types and procedures are found in Chapter 630 of the Highway Design Manual (HDM). The purpose of this guide is to provide some examples of new flexible pavement designs using the procedures for new construction described in HDM Topic 633. Rehabilitation design procedures and strategies for flexible pavement may be found in HDM Topic 635. Examples of rehabilitation designs may be found on the Department pavement website at:

http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm

Flexible pavement design examples included in this guide are:

1. HMA/AB/AS or HMA/CTB-B/AS
2. HMA/CTB-A/AS
3. HMA/ATPB/AB/AS or HMA/HMAB/ATPB/AB/AS
4. HMA/ATPB/AB/AS or full-depth HMA
5. RAC-G/HMA/AB/AS

Where:

HMA – Hot Mixed Asphalt (formerly Asphalt Concrete)
CTB-A – Cement Treated Base Class A
AB – Aggregate Base   CTB-B – Cement Treated Base Class B
AS – Aggregate Subbase   ATPB – Asphalt Treated Permeable Base
CTPB – Cement Treated Permeable Base
HMAB – Hot Mixed Asphalt Base (Type A or B)
RAC-G – Rubberized Asphalt Concrete Type G (Gap Graded)

(1) Design Example 1 - Undrained Pavement structures Designed per California R-values of Underlying Layers (HMA/AB/AS or HMA/CTB-B/AS).

(a) Determine the total pavement structure GE, over the subgrade, using the standard design formula and the California R-value of the subgrade. For this example, assume a subgrade with a California R-value of 10. A TI of 12.5 is assigned based on the traffic forecasts for trucks. Thus, the total required GE is:

$GE_{Total} = 0.975(TI)(100-R_{Subgrade})$; where R is the subgrade California R-value

$= 0.975(12.5)(100-10) = 1097$ mm

(b) Determine the GE of the HMA surface layer using the standard formula. In this case, R is the California R-value of the Class-2 AB layer (see HDM Table 663.1B of the HDM for California R-values of various materials).

$GE_{HMA} = 0.975(TI)(100-R)$; where R is the Class-2 AB California R-value

$GE_{HMA} = 0.975(12.5)(100-78) = 268$ mm

(c) Add the required 60 mm safety factor to the total GE of HMA:

Final $GE_{HMA} = GE_{HMA} + $ Safety Factor $= 268 + 60 = 328$ mm

(d) Use HDM Table 633.1 of the HDM to determine the GE and thickness of the HMA surface layer:

With a TI of 12.5, the closest GE from HDM Table 633.1 is 329 mm for which the required HMA thickness is 195 mm.

(e) Although the calculated GE for the HMA is 328 mm, Table 633.1 of the HDM shows a GE of 329 as nearest to the calculated value. The value from Table 633.1 of the HDM will be used in subsequent calculations for the remaining layers.

(f) Determine the required GE of the combined HMA and AB layers using the standard design formula. In this case, R is the California R-value of the AS layer. For this example, assume a Class 2 AS, which has a specified minimum California R-value of 50 (see Table 663.1B of the HDM).

$GE_{HMA+AB} = 0.975(TI)(100-R) = 0.975(12.5)(100-50) = 609$ mm

where R is the aggregate subbase California R-value

(g) Add the required 60 mm safety factor to this value to determine the GE of the combined HMA and AB.

$GE_{HMA+AB} = GE_{HMA+AB} + $ Safety Factor $= 609 + 60 = 669$ mm

(h) Subtract the GE of the HMA (Step d) from the combined GE of the HMA and AB to determine the required GE of the AB.

$GE_{AB} = GE_{HMA+AB} - GE_{HMA} = 669 - 329 = 340$ mm

Table 633.1 of the HDM shows a value of 347 as the closest value to the calculated GE of 340 mm for the AB layer. The tabular value of 347 will be used in subsequent calculations for which the corresponding AB thickness is 315 mm.

Note

If CTB-B is used in lieu of AB, use HDM Table 633.1 of the HDM to determine actual thickness:

With a GE of 340 mm, HDM Table 633.1 shows CTB-B with a GE value of 342. This corresponds to a layer thickness of 285 mm of CTB-B.

(i) Subtract the GE of the HMA and AB layers, taken from HDM Table 663.1, from the GE of the total pavement structure (Step a) to determine the GE of the AS:

1097 - 329(HMA) - 347(AB) = 421 mm (Round to 420)

Note

If CTB-B is used in lieu of AB, the GE of the AS will be:

1097 - 329(HMA) - 342(CTB-B) = 426 mm (Round to 420)

Since AS has a G_f of 1.0, the actual thickness and the GE are equal.

(j) The structural layer thicknesses for the above example are:

Note   If CTB-B is used:

Layer	Thickness (mm)
HMA	195
AB	315
AS	420

Layer	Thickness (mm)
HMA	195
CTB – B	285
AS	420

(2) Design Example 2 - Undrained Pavement Structures with Materials not Subject to California R-value Tests (HMA/CTB-A/AS).

(a) Determine the total pavement structure GE as described in *(1) (a)* above. Use the same TI and subgrade California R-value as in Design Example 1.

$GE_{Total} = 0.975(TI)(100-R)$; Where R is the subgrade California R-value.

$GE_{Total} = 0.975(12.5)(100-10) = 1097$ mm

(b) To determine the GE of the HMA surface layer when placing a material not subject to the California R-value tests (see HDM Table 663.1B for a list of materials not subject to California R-value tests), calculate the GE of the combined HMA and CTB using the standard design formula and the California R-value of the AS. This is needed because 40% of the GE for the combined HMA and CTB will be used to determine the GE of the HMA, which will lead to the HMA surface layer thickness. In cases where the subgrade is of such quality that AS is not necessary, the California R-value of the subgrade is used. For this example, assume a Class 2 AS with a specified California R-value of 50.

Note: When AS is to be replaced with additional base material, use California R-value 50 in this calculation.

$GE_{HMA+CTB-A} = 0.975(TI)(100-R)$; Where R is the AS California R-value.

$GE_{HMA+CTB-A} = 0.975(12.5)(100-50) = 609$ mm

(c) Determine the GE of the HMA layer by multiplying the GE of the combined HMA and CTB layers by 0.4 and adding the safety factor.

$GE_{HMA} = GE_{HMA+CTB-A}(0.4) + \text{Safety Factor}$

$GE_{HMA} = (609)(0.4) + 60 = 304$ mm

(d) Determine the actual thickness of HMA from Table 633.1 of the HDM.

The closest GE from HDM Table 633.1 is 296 mm which corresponds to an HMA layer thickness of 180 mm. Subsequent calculations will use 296 mm as the GE of the HMA.

(e) To determine the GE of the CTB -A layer, add the safety factor to the GE of the combined HMA and CTB layers (step b above) and subtract the GE of the HMA surface layer (step d above).

$GE_{CTB-A} = GE_{HMA+CTB-A} + \text{Safety Factor} – GE_{HMA}$

$GE_{CTB-A} = 0.975(TI)(100-R) + \text{Safety Factor} - GE_{HMA}$; Where R is the AS California R-value.

$GE_{CTB-A} = 0.975(12.5)(100-50) + 60 \text{ mm} – 296 \text{ mm}$

$= 609 \text{ mm} + 60 \text{ mm} – 296 \text{ mm} = 373 \text{ mm}$

(f) The closest GE from HDM Table 633.1 is 383 mm which corresponds to a CTB –A layer thickness of 225 mm. Subsequent calculations will use 383 mm as the GE of the CTB – A.

(g) Subtract the GE of the HMA and the CTB –A from the total GE over the subgrade to determine the GE of the AS layer.

1097(total) – 296(HMA) – 383(CTB CL-A) = 418 mm (Round to 420)

(h) The pavement structural layer thicknesses for the above example are:

| Layer	Thickness (mm)
HMA	180
CTB (CL - A)	225
AS	420

I-15 at Baker Grade (1961)

(3) **Design Example 3 - Drained Pavement Structures Which Include Treated Permeable Bases. (HMA/ATPB/AB/AS or HMA/HMAB/ATPB/AB/AS):**

Note: The efficiency of the drainage layer can be affected by a lack of continuity in the treated permeable base across the width of the traveled way. To help assure adequate drainage on a multilane facility, the flexible pavement and the treated permeable base layers should not be stepped to accommodate differences in TIs of adjacent lanes. Reducing the base and/or subbase layer as appropriate to satisfy the GE requirement over the subgrade can compensate for the resulting overdesign of the flexible pavement in the median lanes.

(a) Determine the total pavement structure GE as described in Design Example *(1) (a)* above. Use the same TI and subgrade California R-value as in previous design examples.

GE $_{Total}$ = 0.975 (TI) (100-R); Where R is the subgrade California R-value.

GE $_{Total}$ = 0.975(12.5) (100-10) = 1097 mm
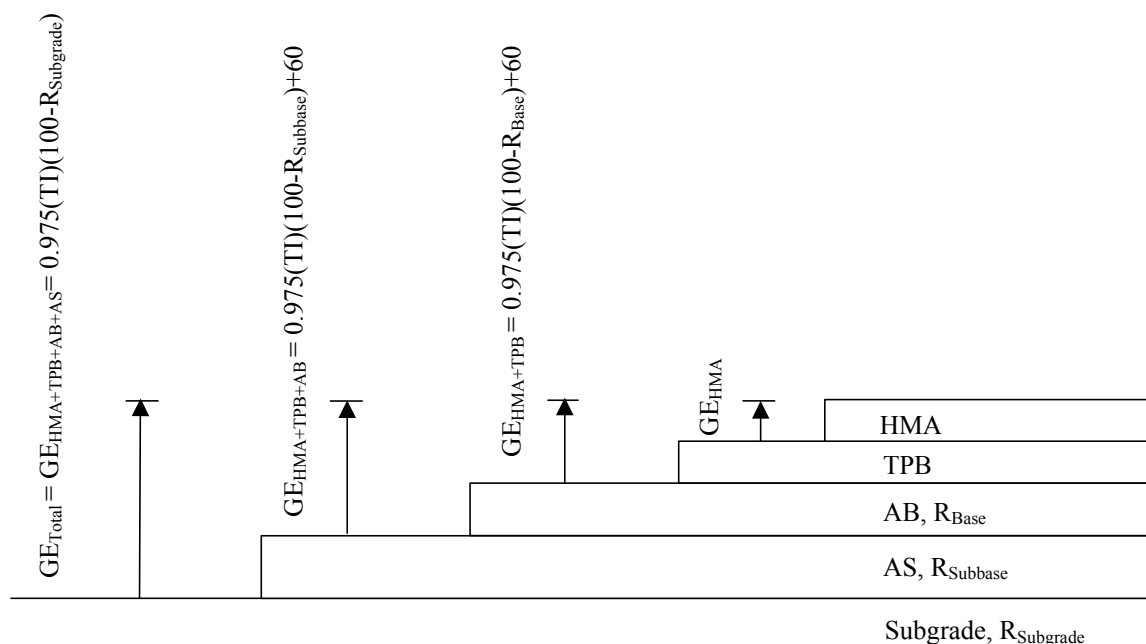
(b) Determine the GE of the combined HMA, treated permeable base (TPB), and base using the standard design formula and the California R-value of the AS. This also follows the rule that 40% of the GE above the AS will be used for the HMA surface layer thickness calculations. In this example, Class 2 AS with a specified California R-value of 50 is assumed.

Note: When AS is to be replaced with additional base material, use California R-value of 50 in this calculation.

6

$GE_{HMA + TPB + AB} = 0.975$ (TI) $(100\text{-}R_{Subbase})$

$GE_{HMA + TPB + AB} = 0.975(12.5)(100\text{-}50) = 609$ mm

(c) Determine the GE of the HMA surface layer by multiplying the required GE of the combined HMA, treated permeable base and base layers by 0.4 and adding the safety factor. On multiple lane roadways, the HMA thickness is constant for all lanes and is based on the TI of the outside lanes.

$GE_{HMA} = (GE_{HMA + TPB + AB})(0.40) + 60$ mm $= (609$ mm$)(0.40) + 60$ mm $= 304$ mm

(d) The closest GE from Table 633.1 is 296 mm which corresponds to an HMA surface layer thickness of 180 mm. Subsequent calculations will use 296 mm as the GE of the HMA.

(e) The GE for Asphalt Treated Permeable Base (ATPB) is 105 mm for a corresponding 75 mm layer thickness of ATPB. For Cement Treated Permeable Base (CTPB), the GE is 180 mm for a corresponding 105 mm layer thickness of CTPB. ATPB is used in this example.

$GE_{ATPB} = 105$ mm $= 75$ mm thickness for ATPB

(f) Determine the required GE of the base layer by adding the 60 mm safety factor to the GE required over the AS (as shown in 3b above) and then subtracting the GE of the combined HMA and treated permeable base layers.

$GE_{AB} = GE_{HMA + ATPB + AB} - GE_{HMA} - GE_{ATPB} + 60$ mm

$GE_{AB} = 609$ mm $- 296$ mm $- 105$ mm $+ 60$ mm $= 268$ mm

(g) The closest GE from HDM Table 633.1 for AB is 264 mm, which corresponds to an AB layer thickness of 240 mm. Subsequent calculations will use 264 as the GE of the AB.

$GE_{AB} = 264$ mm (From Table 633.1 of the HDM)

(h) Determine the required GE thickness of the AS by subtracting the tabular values from Table 633.1 of the HDM for the GE thickness of the combined HMA, permeable base, and base layers from the total GE required for the pavement structure (as shown in 3a above).

$GE_{AS} = GE_{Total} - (GE_{HMA} + GE_{ATPB} + GE_{AB})$
$GE_{AS} = 1097$ mm $- (296$ mm $+ 105$ mm $+ 264$ mm$) = 1097$ mm $- 665$ mm $= 432$ mm
$GE_{AS} = 432$ mm (Round up to 435 mm)

Note:

As an alternative, hot mixed asphalt base (HMAB) can be substituted for other HMA types in the pavement structure on an equal basis but is not to be used as the surface course. HMAB is a dense graded HMA material and differs from other HMA in that it includes aggregates with a larger nominal size. Thus, if 45 mm were chosen for the HMA surface course then an HMAB layer thickness of 135 mm would be used.

Layer	Alternative 1 (mm)	Alternative 2 (mm)
HMA	180	45
HMAB	-----	135
ATPB	75	75
AB	240	240
AS	435	435

(4) **Design Example 4 (HMA/ATPB/AB/AS or full-depth HMA):**

An additional lane is to be added adjacent to an existing pavement structure, which has a total thickness of 830 mm consisting of 180 mm HMA, 75 mm ATPB, 150 mm CTB, and 425 mm AS. The new lane has a projected TI of 12.5 and will be constructed over a subgrade with a California R-value of 10. Full-depth HMA provides a viable alternative since it will reduce the number of construction layers and the time required to complete the project. The GE of the HMA is 1097 mm. A safety factor of 30 mm is added to bring the total GE to 1127 mm.

$GE_{HMA} = 0.975(TI) (100-R) + \text{Safety Factor} = 0.975(12.5) (100-10) + 30 \text{ mm} = 1127 \text{ mm}$

The closest GE from Table 633.1 of the HDM is 1140 mm with a corresponding HMA thickness of 495 mm. This thickness will greatly reduce the total pavement structure thickness compared to example three above and as shown below:

Layer	Design Example 3 Alternative 1 (mm)	Design Example 6 Full-Depth HMA (mm)
HMA	180	495
ATPB	75	----
AB	240	----
AS	435	----
Total Thickness (mm)	930	495

When a minimum 105 mm working table of AS is placed below the HMA the GE for the HMA is reduced to 1022 mm.

When a drainage layer is included with the HMA and AS, the GE of the HMA is further reduced by an amount equal to the GE of the drainage layer. In this example, assume a 75 mm layer of ATPB (GE of 105) and an AS working table thickness of 105 mm (GE of 105 mm). Thus, the GE and thickness of the HMA are reduced as follows:

$GE_{HMA} = GE_{Full-Depth\ HMA} - GE_{ATPB} - GE_{AS}$

$GE_{HMA} = 1127\ mm - 105\ mm - 105\ mm = 917\ mm$

The closest GE from Table 633.1 of the HDM is 916 mm with a corresponding HMA thickness of 420 mm.

To assure continuity of the drainage layer between the existing and new pavements the ATPB should be placed at the same level as the ATPB in the existing lane. In this example, the ATPB would be placed beneath the top 180 mm of HMA. Thus, the pavement structure for the additional lane would be 180 mm HMA, 75 mm ATPB, 240 mm HMA, and 105 mm AS.

When full depth HMA is placed, adequate cooling of each compacted layer prior to placing additional lifts is necessary to prevent rutting. The time needed to ensure adequate cooling is achieved, must be considered when developing allowable work hours for lane closure charts.

(5) Design Example 5 (RAC -G/HMA/AB/AS):

Rubberized Asphalt Concrete (RAC) is usually placed on rehabilitation projects as an overlay and in some instances as the surface course for the new construction. For requirements and practices on the use of RAC, see HDM Index 631.1 and the Asphalt Rubber Usage Guide on the Department Pavement website:

http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm

RAC thicknesses are determined by first calculating the HMA thickness and then converting it to RAC. Taking the results from Example 1 of the guide and Index 631.3 of the HDM, up to 60 mm of RAC may be substituted for 60 mm of HMA (1:1 ratio), resulting in the following modification of the Example 1 Alternative:

Layer	Design Example 1 Dense Graded HMA Alternative (mm)	Design Example 7 RAC Alternative (mm)
RAC	----	60
HMA	195	135
AB	315	315
AS	420	420
Total Thickness (mm)	930	930

Note that the use of RAC-G does not reduce the overall pavement structure thickness in a new construction design. Although typically more expensive, early indications from research and experience with RAC seem to show that the longevity of the pavement will improve with a RAC surface course. So, whereas it may not save on initial construction costs, it may reduce life cycle costs. Studies are currently underway to verify and quantify this benefit.

To determine if RAC is a better solution, a life cycle cost analysis should be done between HMA and RAC during the project development process. The "Life Cycle Cost Procedures Manual" provides procedures and information to complete this analysis and can be found on the Department Pavement web site at:

http://www.dot.ca.gov/hq/oppd/pavement/guidance.htm